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Impact of Energy Efficiency and Financial Support on Green Upgrading in China's Industrial Sector

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Abstract: The report from the 20th National Congress of China emphasizes the importance of focusing on the clean, low-carbon, and efficient use of energy, increasing financial support, and promoting green upgrading within the industrial sector. This paper, based on annual data, employs the entropy weight method to construct a comprehensive index reflecting the impact of green upgrading in industrial sectors. To delve deeper, it utilizes the DEA model to measure energy efficiency and its subdivision BCC model to break down energy efficiency into technical and scale efficiency. The financial support landscape is examined from the vantage points of both direct and indirect financing. Using a multivariate time series model, this paper thoroughly investigates the influence of energy efficiency and financial support on the green upgrading of the industrial sector. The findings reveal a significant positive impact of both energy efficiency and financial support on green upgrading in industrial industries. Notably, scale efficiency emerges as the primary driver of energy efficiency. Moreover, indirect financing proves to be more effective in promoting financial support than direct financing. The empirical results retain their robustness even after substituting explanatory variables. The study concludes by contextualizing the research findings within the current real-world scenario, offering practical insights, and proposing specific recommendations.

Keywords: Energy efficiency; Financial support; Industrial green upgrading; DEA-BCC model

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1. Introduction

China has actively engaged in global climate change governance. experiencing remarkable growth over the past few decades. However, this success has presented certain challenges. Due to the current stage of development, China's industrial production has predominantly relied on a resource-intensive and high-pollution growth model, leading to relatively low industrial efficiency and severe environmental pollution. With growing attention from both the government and society on environmental issues in recent years, addressing pollution and accomplishing a green transformation and upgrade of the industrial sector has become imperative.

The economic essence of industrial green upgrading can be defined as a high-level overhaul of the industrial structure, involving a continual rise in the proportion of industries producing high-value-added products and a general increase in value-added products across various industrial sectors. Existing research

indicates that the green upgrading of industrial industries can effectively reduce industrial energy consumption, diminish industrial pollution, and contribute to the attainment of carbon peaking and carbon neutrality.

In the ongoing efforts to promote and develop the green transformation and upgrading of industrial industries, the significance of energy efficiency and financial support has become increasingly prominent. Clarifying these aspects is crucial for achieving the green transformation of industrial industries.

2. Review of domestic and international research

Presently, there exists a significant body of research on the green upgrading of industries, predominantly focusing on two main aspects: the theory of industrial green upgrading and the impact of energy efficiency and financial support on industrial green upgrading.

Drawing on scholarly work, Chuanwang Sun and Wenyue Zhang developed a twelve-indicator system for industrial green upgrading, encompassing three dimensions: technological innovation, structural upgrading, and energy saving and emission reduction [1]. They measured the comprehensive index of industrial green upgrading effect, offering a more comprehensive depiction of the distribution dynamics in the evolution of industrial green upgrading levels and the overall status of regional industrial green transformation nationwide [1]. Zongbing Deng *et al*. established a five-dimensional industrial green development level index system that includes green total, green innovation, green efficiency, green security, and green governance [2].

Regarding the impact of energy efficiency and financial support on the green upgrading of industries, some scholars' research suggests that energy efficiency exerts a positive influence on industrial green upgrading [3,4]. Liang-Jun Wang *et al*. argued that industrial energy efficiency is pivotal for achieving energy transformation, carbon emission reduction, and promoting industrial green transformation [5]. Karasek *et al*. employed data envelopment analysis (DEA) to evaluate energy efficiency in European Union (EU) countries from a dynamic perspective [6].

In summary, the combination of energy efficiency and financial support to explore the operational mechanism of achieving green upgrading in industrial sectors from two perspectives holds both theoretical and practical significance.

3. Research design

3.1. Variable selection

In the realm of energy efficiency indicators, careful consideration is given to the pivotal variable of financial support. Input variables encompass energy consumption and labor, while industrial GDP stands as the output variable. China's energy efficiency is gauged through DEAP2.1. The financial support dimension encompasses credit and securities, with Nanan Cao *et al*. opting to measure financial support through loan size and [7], drawing inspiration from Nan Li [8], in terms of stock market capitalization. Green upgrade indicators, derived from Sun and Zhang [1], describe the effect of industrial green upgrading, extending to two indicators: innovation input and innovation output. The data undergo standardization using the dimensionless method, and weights are assigned to the indicators through the entropy weighting method to measure the comprehensive index of the green upgrading effect. In alignment with existing research, this paper introduces a set of control variables into the benchmark model to mitigate any potential omitted variable bias.

3.2. Econometric model construction

Utilizing macroeconomic data collected from 2005 to 2020 in China, a multivariate time series is chosen to

unravel the effects of energy efficiency and financial support on the green upgrading of industrial industries. The regression model is set as follows:

In this equation, *IGTE* represents the industrial green upgrade effect, *Efficiency* signifies energy efficiency, *LS* denotes loan size, *SV* stands for stock market value, *X* encompasses a set of control variables, including industry size, environmental regulation, and the degree of openness to the outside world, and $\varepsilon_{(t)}$ is the random disturbance term.

Interpreting the equation, the subscripts signify the time dimension. Coefficients measure the effects of energy efficiency and financial support on industrial green upgrading. A significantly positive coefficient for energy efficiency implies that it enhances the effect of industrial green upgrading. Meanwhile, a positive coefficient for financial support, considering loan size and stock market value, suggests that financial support contributes to the conclusion of industrial green upgrading. The adoption of the logarithmic form aids in addressing the non-stationarity of time series data and mitigates heteroskedasticity. Additionally, it provides economic insights into the elasticity of estimated parameters, enhancing the model's interpretability.

4. Empirical results and analysis

4.1. Benchmark model regression analysis

To ensure the availability and relevance of sample data, this paper conducts empirical analysis using national macroeconomic data from 2005 to 2020. In the model selection process, two types of models were employed: Model I, which excludes control variables, and Model II, which comprehensively incorporates the impact of each control variable on the dependent variable. The empirical results, generated by StataMP17, are summarized and organized in **Table 1**.

Table 1. Empirical test results on the factors influencing industrial green upgrading

Variables	Model I	Model II
ln *Efficiency*	2.2859*** (0.20)	2.3673*** (0.23)
ln *LS*	0.6828*** (0.15)	0.6392** (0.16)
ln *SV*	0.0489* (0.03)	0.0681** (0.03)
Scale		-5.93e-07* (3.03e-07)
Open		-0.1352 (0.26)
Regulation		-0.1058 (15.01)
Constant	-2.7136*** (0.06)	-2.4680*** (0.15)
R^2	0.9920	0.9946
F Statistic	496.74	277.83
Observed values	16	16
D.W. values	1.1974	1.4111

Note: The standard errors in parentheses are represented by *, **, and ***, respectively, which represent significant values at the 10%, 5%, and 1% levels.

Upon comparing and analyzing the regression results of the two models presented in **Table 1**, it becomes evident that the positive effect of loan scale on industrial green upgrading surpasses that of stock market value on the same. This indicates that the influence of indirect financing support from financial institutions, such as

banks, in the industrial sector is more substantial than that of direct financing support from the capital market. The estimation results shed light on the challenges and limitations faced by the industrial sector in securing financial support through direct financing methods such as issuing stocks to promote enterprise development, as opposed to the relatively more accessible channels of indirect financing, such as loans from financial institutions.

4.2. Residual sequence autocorrelation test

An autocorrelation test was executed on the residuals derived from the regression results of Model II, as detailed in **Table 2**. The first 12-order autocorrelation coefficients were found to be significantly 0 at the 5% level. This suggests an absence of autocorrelation in the sequence, affirming that the model did not overlook key variables and aligns with the stipulated model requirements.

Table 2. Residual autocorrelation data

Order Number	AC	PAC	Q-Stat	Prob
1	0.252	0.252	1.2161	0.270
2	0.172	0.116	1.8262	0.401
3	-0.275	-0.371	3.5028	0.320
4	-0.070	0.078	3.6216	0.460
5	-0.155	-0.045	4.2488	0.514
6	-0.065	-0.148	4.3695	0.627
7	-0.343	-0.334	8.1289	0.321
8	-0.266	-0.185	10.679	0.221
9	-0.203	-0.057	12.380	0.193
10	0.068	-0.048	12.602	0.247
11	0.191	0.051	14.707	0.196
12	0.101	-0.169	15.444	0.218

To bolster the reliability of the regression results, a robustness test is employed using the variable replacement method. In this instance, the explanatory variable indicator system undergoes a substitution wherein the number of industrial sector patents is replaced with the number of industrial sector patent applications. Additionally, the number of per capita industry patents is substituted with the number of per capita industry patent applications for innovation output. Similarly, the entropy weight method is applied to assign values to the innovation input, and the green upgrading effect index of the industrial sector is recalculated.

Upon reviewing the organized results, it becomes apparent that this modification supports the conclusion that energy efficiency and financial support exert a positive impact on the green upgrading of the industrial sector. This further reinforces the robustness and validity of the research findings.

5. Conclusions

Drawing on theoretical research, this paper constructs a multiple time series model and conducts empirical analysis on the impact of energy efficiency and financial support on the green upgrading of industrial sectors. The following conclusions emerge:

(1) Energy efficiency impact:
- The enhancement of energy efficiency exhibits a significantly positive effect on the green upgrading of the industrial sector.
- This underscores the substantial promoting influence of energy efficiency on the green upgrading of the industrial sector.
- The driving factors behind this positive impact include effective energy conservation, alleviating challenges posed by energy depletion, and ensuring normal daily production operations within the industrial sphere.
- The process of improving energy efficiency often intertwines with technological innovation, resulting in reduced pollution emissions, improved pollution treatment, and a shift towards green production, ultimately fostering the overall green upgrading of the industrial sector.

(2) Loan scale impact:
- The scale of loans demonstrates a positive effect on the green upgrading of the industrial sector.
- Indirect financing through loans plays a pivotal role in promoting the green upgrading of the industrial sector.
- Possible explanations include commercial banks' rigorous control over fund flows, active implementation of green credit-related policies, and effective allocation of funds to support industrial green upgrading.
- Post-loan supervision and management by commercial banks ensure that funds are utilized to promote green upgrading.
- In response to national and governmental calls, commercial banks actively promote the development and utilization of new energy projects, contributing to novel approaches for industrial green upgrading.

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